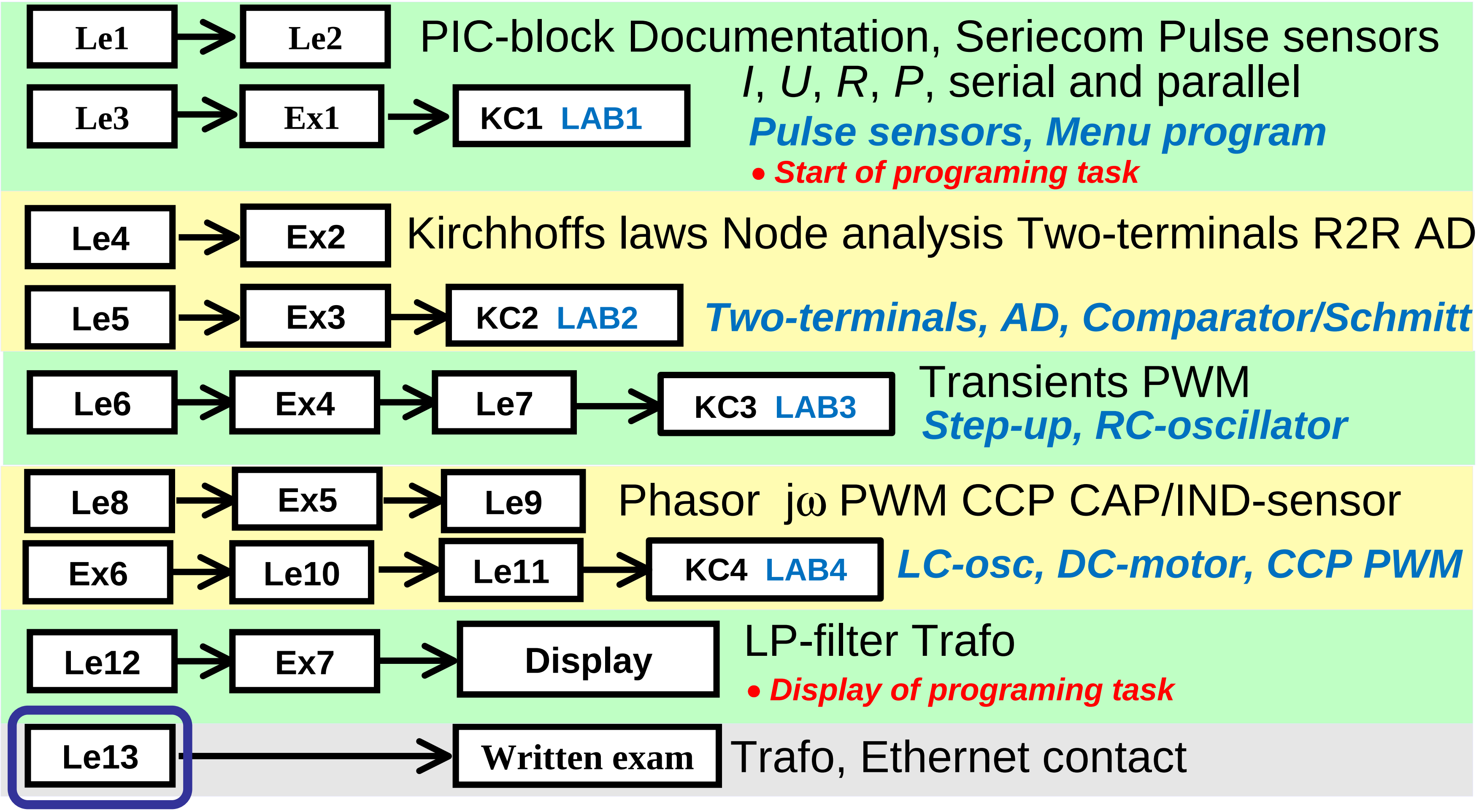
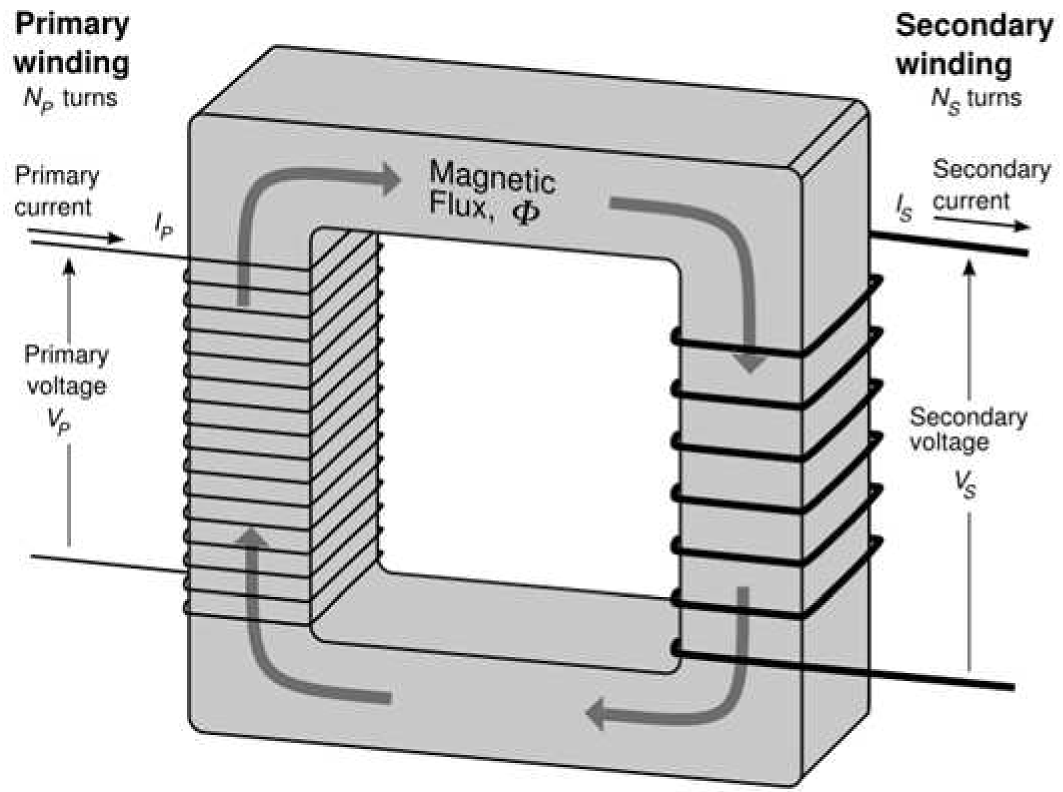
IE1206 Embedded Electronics



William Sandqvist william@kth.se

Transformer

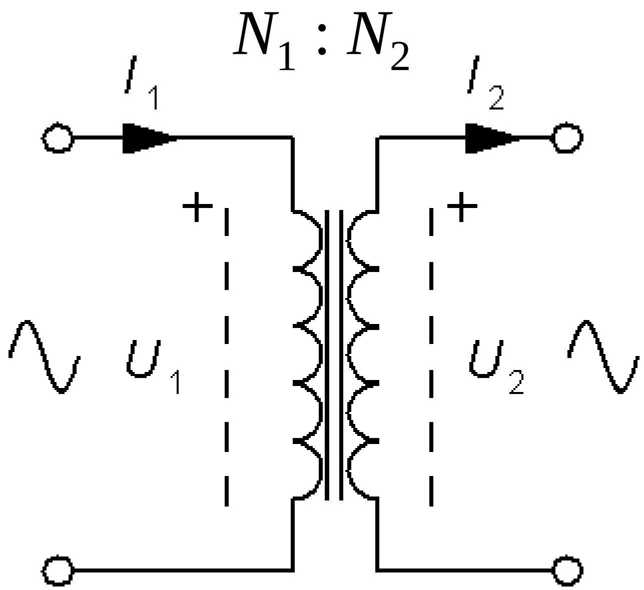


William Sandqvist william@kth.se

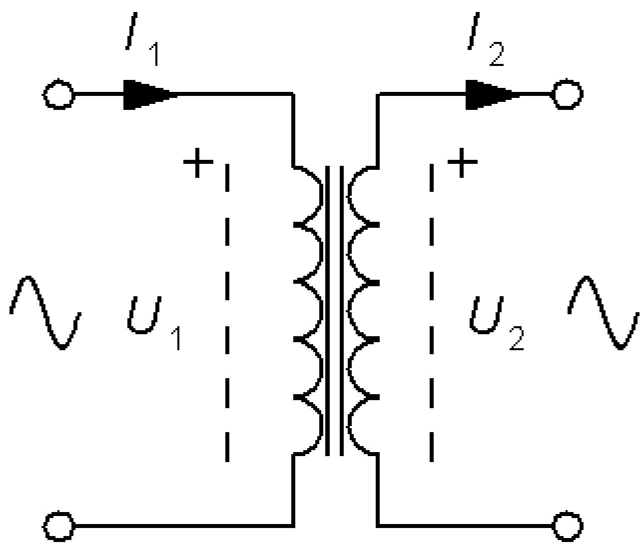
Voltage ratio

$$U_1 = N_1 \frac{\mathrm{d}\Phi}{\mathrm{d}t} \quad U_2 = N_2 \frac{\mathrm{d}\Phi}{\mathrm{d}t}$$

$$\boxed{\frac{U_1}{U_2} = \frac{N_1}{N_2}}$$



Ideal transformer $I_0 = 0$



$$N_1 \cdot I_0 = N_1 \cdot I_1 - N_2 \cdot I_2$$

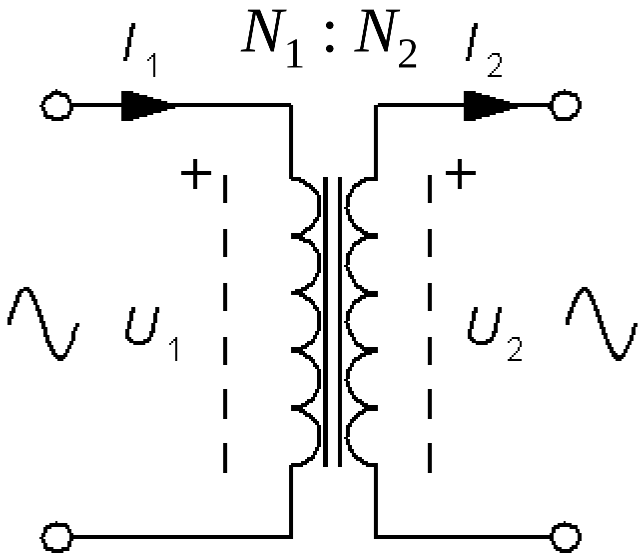
Magnetisig current $I_0 \approx 0$ is *small* compared to the work currents I_1 and I_2. The transformer itself has a high inductance.

Current ratio

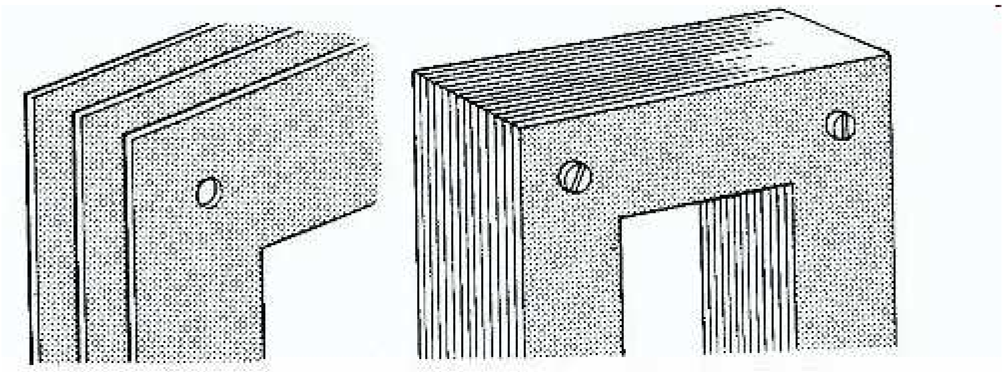
$$P_1 = P_2 \quad (P_0, I_0 = 0)$$

$$U_1 \cdot I_1 = U_2 \cdot I_2 \quad \Rightarrow$$

$$\boxed{\frac{I_2}{I_1} \approx \frac{U_1}{U_2} = \frac{N_1}{N_2}}$$

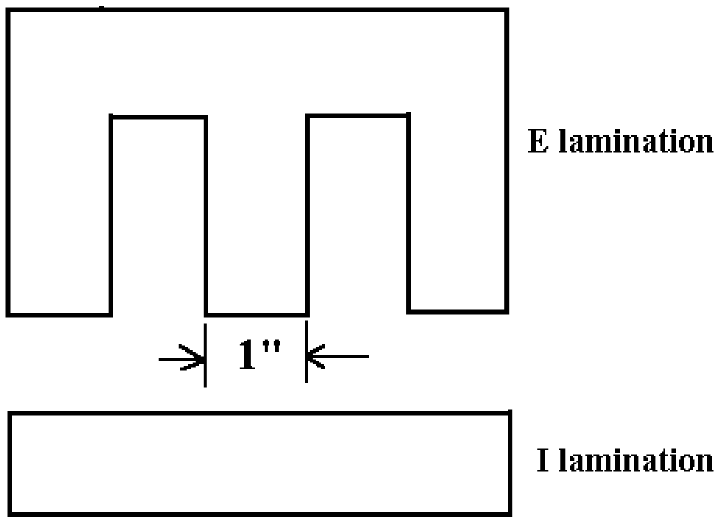


Eddy current losses



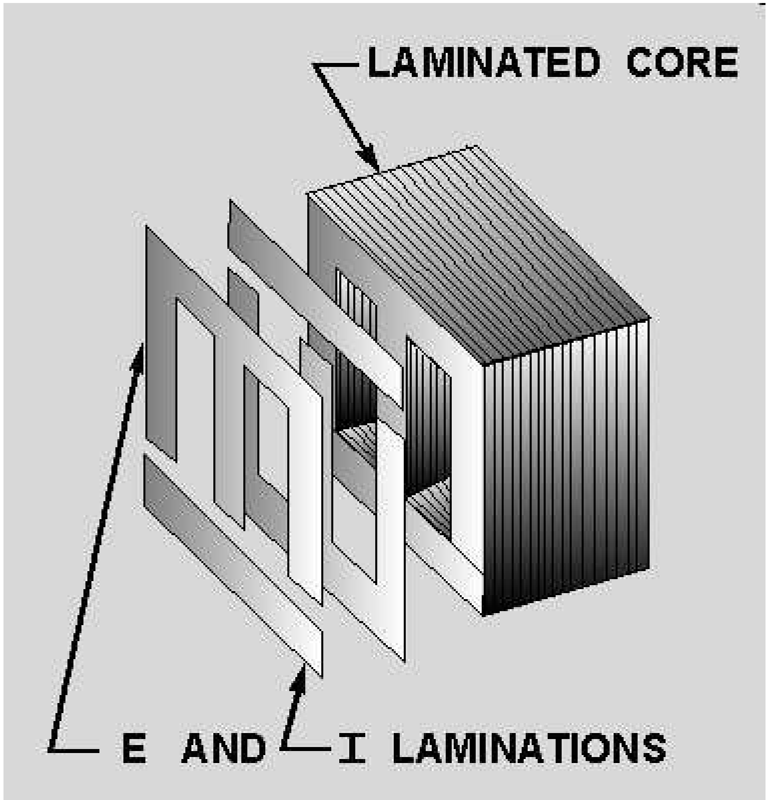
Eddy currents – currents inside the iron core is prevented with lacquered (= isolation) sheet metal.

E I -core



- EI-core is very economical to manufacture !

E I -core

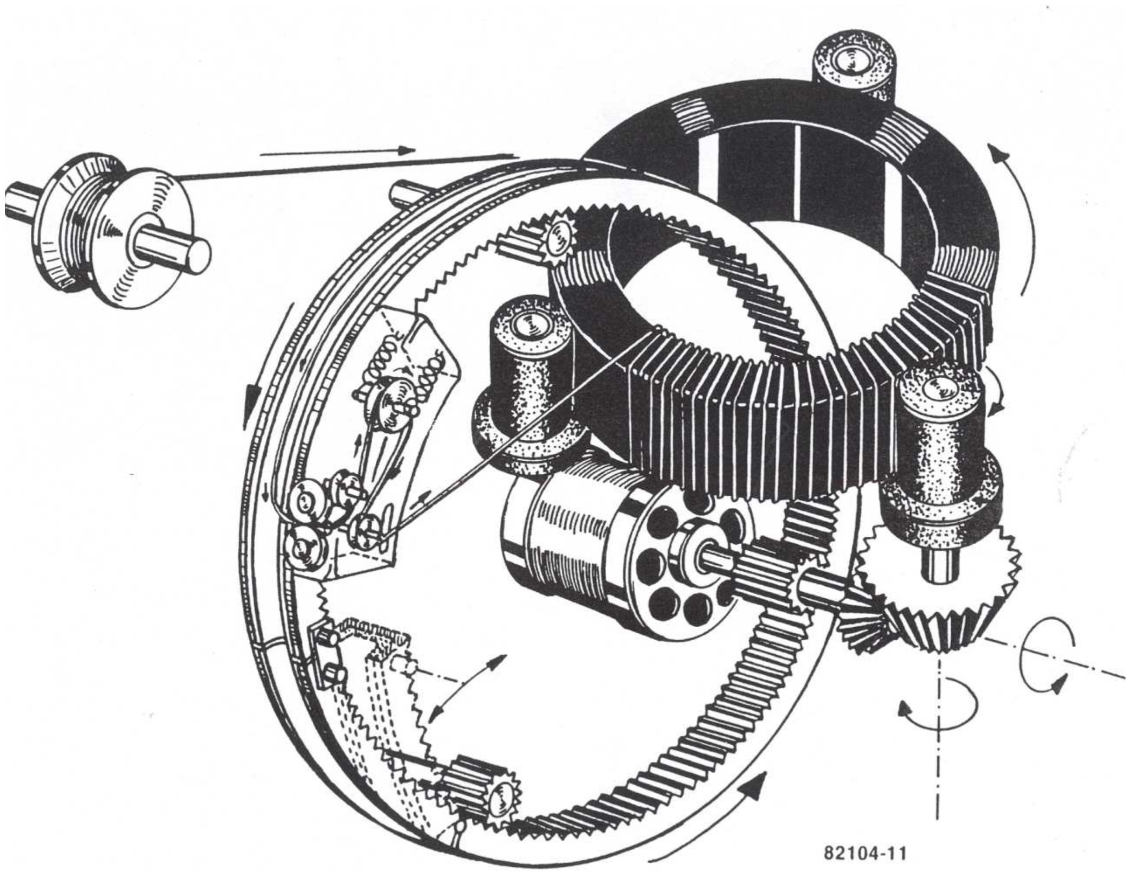


Toroid

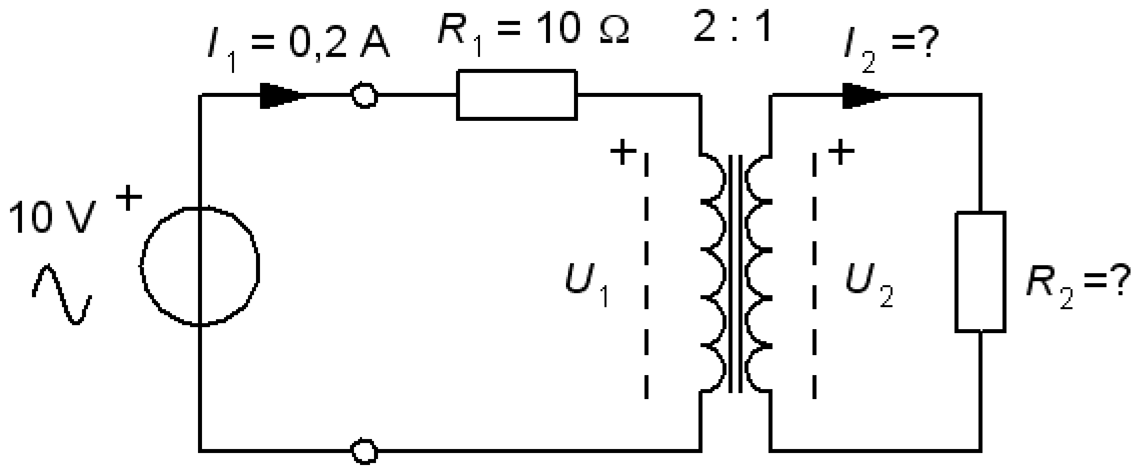
Toroid core has a low leakage field – so it will not disturb nearby electronics!

How do one wind such a transformer?

Automatic Winding of toroidal core

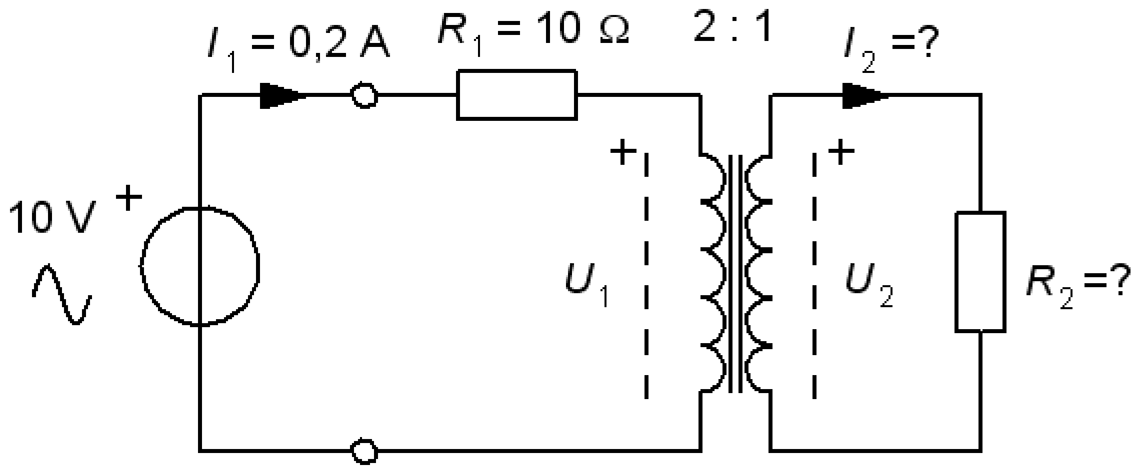


Transformer (15.4)



William Sandqvist william@kth.se

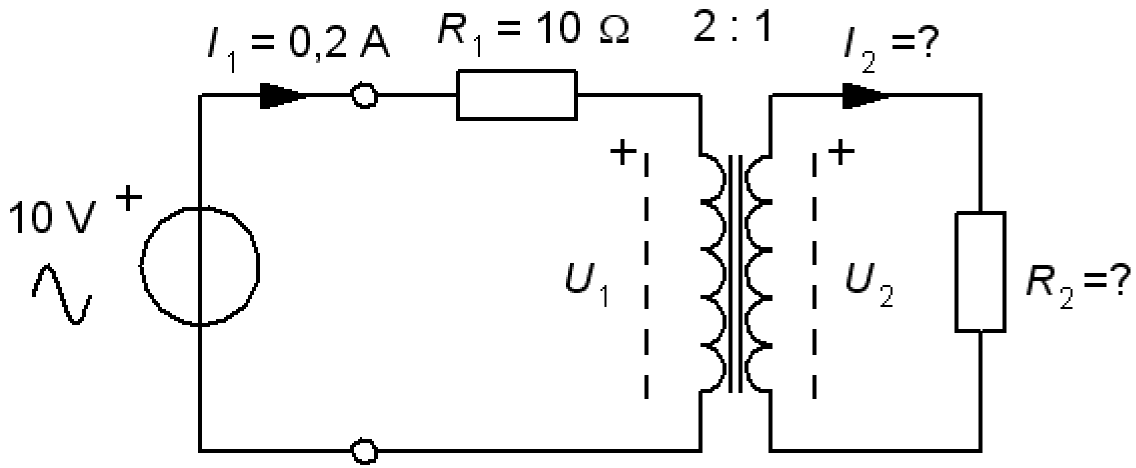
Transformer (15.4)



$$\frac{U_1}{U_2} = \frac{2}{1} \quad \Rightarrow$$

$$\frac{I_1}{I_2} = \frac{1}{2}$$

Transformer (15.4)



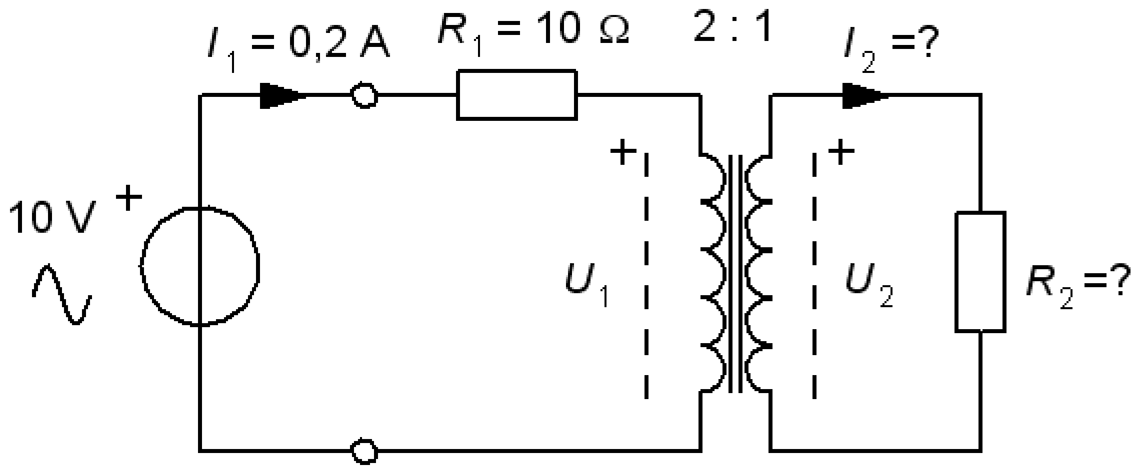
$$\frac{U_1}{U_2} = \frac{2}{1} \quad \Rightarrow$$

$$\frac{I_1}{I_2} = \frac{1}{2}$$

$$10 - R_1 \cdot I_1 - U_1 = 0 \quad \Rightarrow \quad U_1 = 10 - 0{,}2 \cdot 10 = 8$$

William Sandqvist william@kth.se

Transformer (15.4)



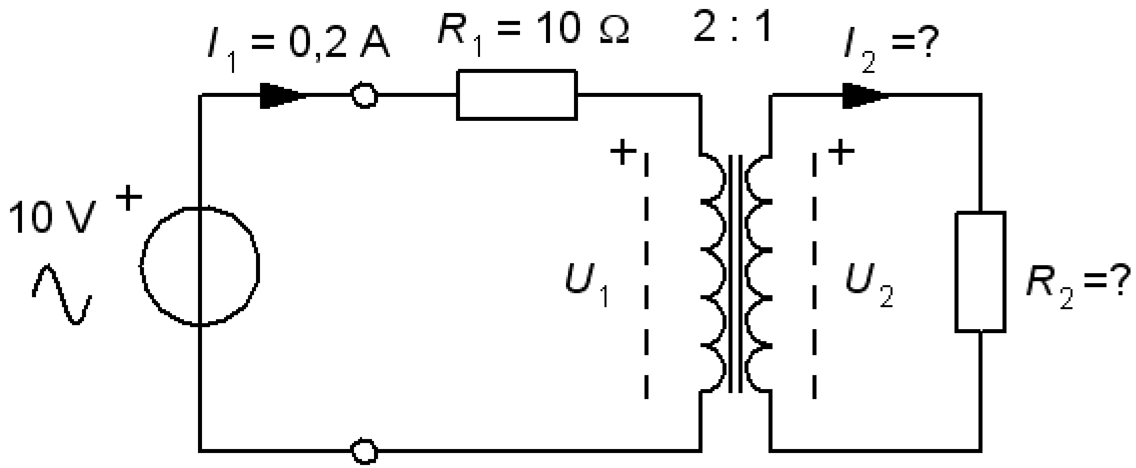
$$\frac{U_1}{U_2} = \frac{2}{1} \quad \Rightarrow$$

$$\frac{I_1}{I_2} = \frac{1}{2}$$

$$10 - R_1 \cdot I_1 - U_1 = 0 \quad \Rightarrow \quad U_1 = 10 - 0{,}2 \cdot 10 = 8$$

$$U_2 = U_1 \cdot \frac{1}{2} = \frac{8}{2} = 4$$

Transformatorn (15.4)



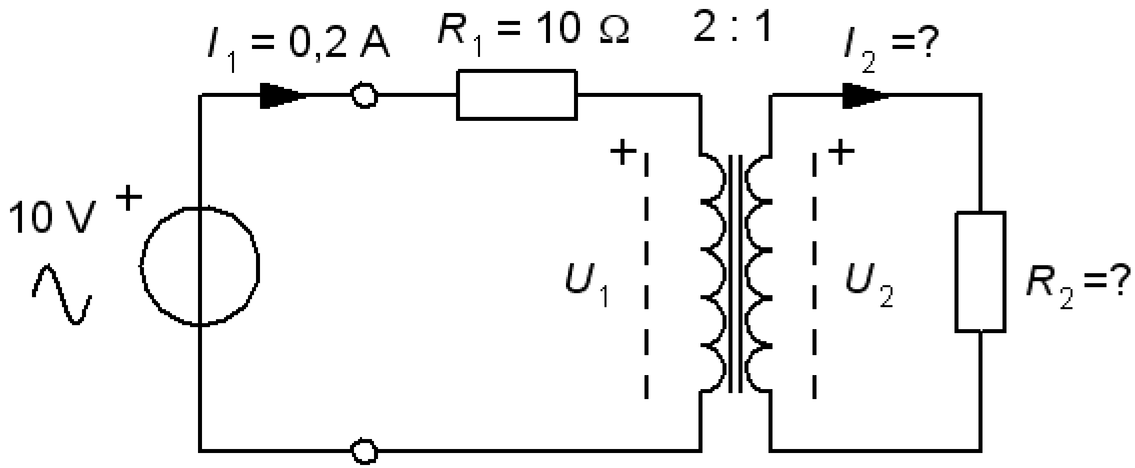
$$\frac{U_1}{U_2} = \frac{2}{1} \quad \Rightarrow$$

$$\frac{I_1}{I_2} = \frac{1}{2}$$

$$10 - R_1 \cdot I_1 - U_1 = 0 \quad \Rightarrow \quad U_1 = 10 - 0{,}2 \cdot 10 = 8$$

$$U_2 = U_1 \cdot \frac{1}{2} = \frac{8}{2} = 4 \qquad I_2 = I_1 \cdot \frac{2}{1} = 0{,}4$$

Transformer (15.4)



$$\frac{U_1}{U_2} = \frac{2}{1} \quad \Rightarrow$$

$$\frac{I_1}{I_2} = \frac{1}{2}$$

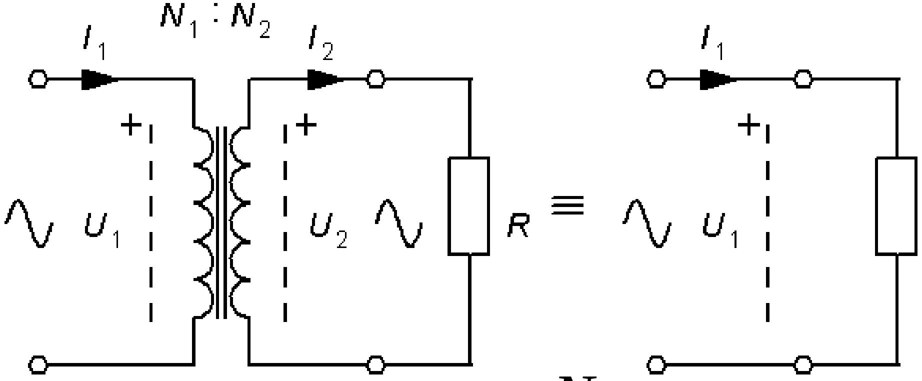
$$10 - R_1 \cdot I_1 - U_1 = 0 \quad \Rightarrow \quad U_1 = 10 - 0{,}2 \cdot 10 = 8$$

$$U_2 = U_1 \cdot \frac{1}{2} = \frac{8}{2} = 4 \qquad I_2 = I_1 \cdot \frac{2}{1} = 0{,}4$$

$$R_2 = \frac{U_2}{I_2} = \frac{4}{0{,}4} = 10\ \Omega$$

William Sandqvist william@kth.se

Transforming impedances



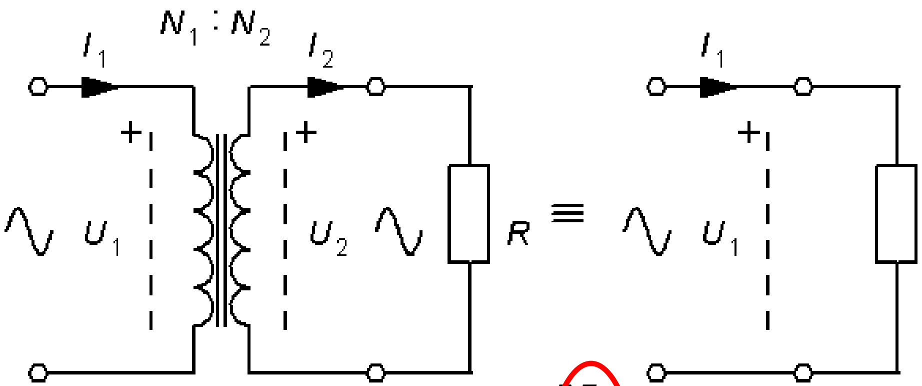
$$\left(\frac{N_1}{N_2}\right)^2 \cdot R$$

$$R_1 = \frac{U_1}{I_1} \quad R_2 = \frac{U_2}{I_2} \quad \frac{U_1}{I_1} = \frac{\frac{N_1}{N_2}U_2}{\frac{N_2}{N_1}I_2} = \left(\frac{N_1}{N_2}\right)^2 \cdot \frac{U_2}{I_2}$$

$$R_{1\leftarrow 2} = \left(\frac{N_1}{N_2}\right)^2 \cdot R_2$$

William Sandqvist william@kth.se

Transforming impedances



$$\left(\frac{N_1}{N_2}\right)^2 \cdot R$$

$$R_1 = \frac{U_1}{I_1} \qquad R_2 = \frac{U_2}{I_2} \qquad \frac{U_1}{I_1} = \frac{\frac{N_1}{N_2} U_2}{\frac{N_2}{N_1} I_2} = \left(\frac{N_1}{N_2}\right)^2 \cdot \frac{U_2}{I_2}$$

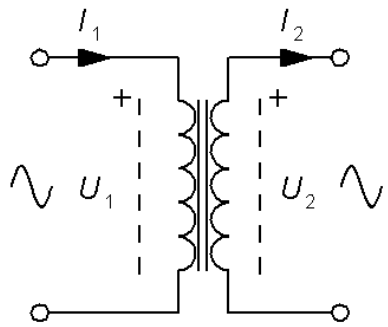
$$\boxed{R_{1 \leftarrow 2} = \left(\frac{N_1}{N_2}\right)^2 \cdot R_2}$$

William Sandqvist william@kth.se

Ex. Transforming impedances

A transformer has the voltage ratio 240V/120V.

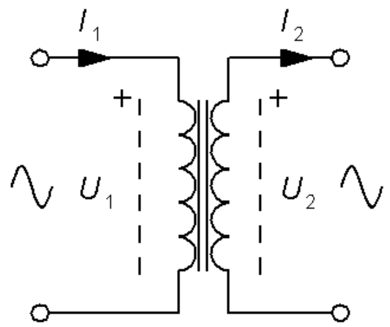
We have two capacitors 1μF and 16 μF. How should one connect to get 5 μF ?



Ex. Transforming impedances

A transformer has the voltage ratio 240V/120V.

We have two capacitors 1μF and 16 μF. How should one connect to get 5 μF ?



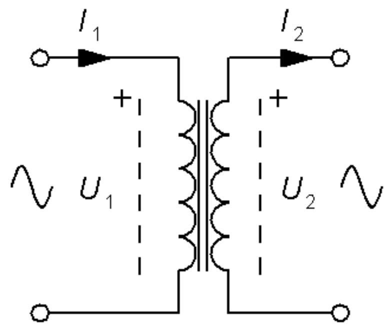
$$Z_2 = \frac{1}{\omega C} \quad \Rightarrow$$

$$Z_{1\leftarrow 2} = \frac{1}{\omega C} \cdot 2^2 = \frac{1}{\omega (C/4)}$$

Ex. Transforming impedances

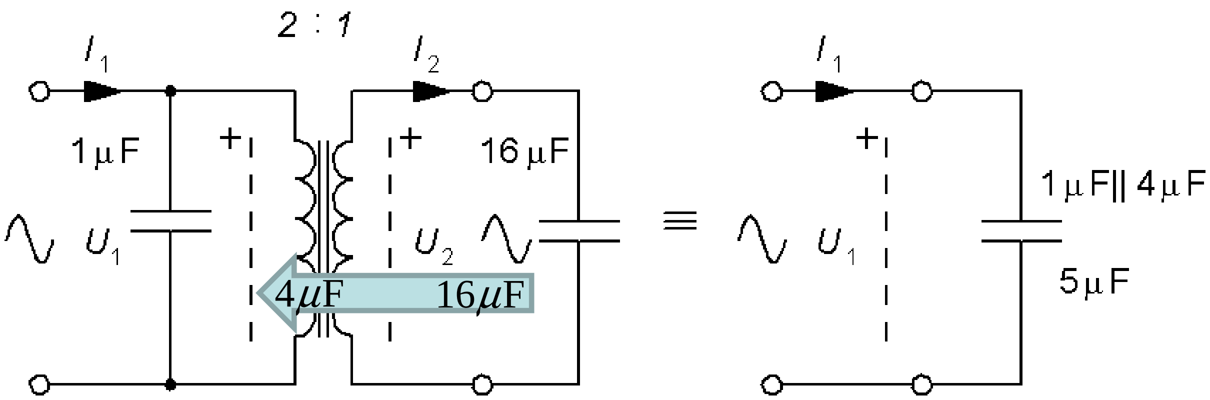
A transformer has the voltage ratio 240V/120V.

We have two capacitors 1μF and 16 μF. How should one connect to get 5 μF ?



$$Z_2 = \frac{1}{\omega C} \quad \Rightarrow$$

$$Z_{1\leftarrow 2} = \frac{1}{\omega C}\cdot 2^2 = \frac{1}{\omega (C/4)}$$

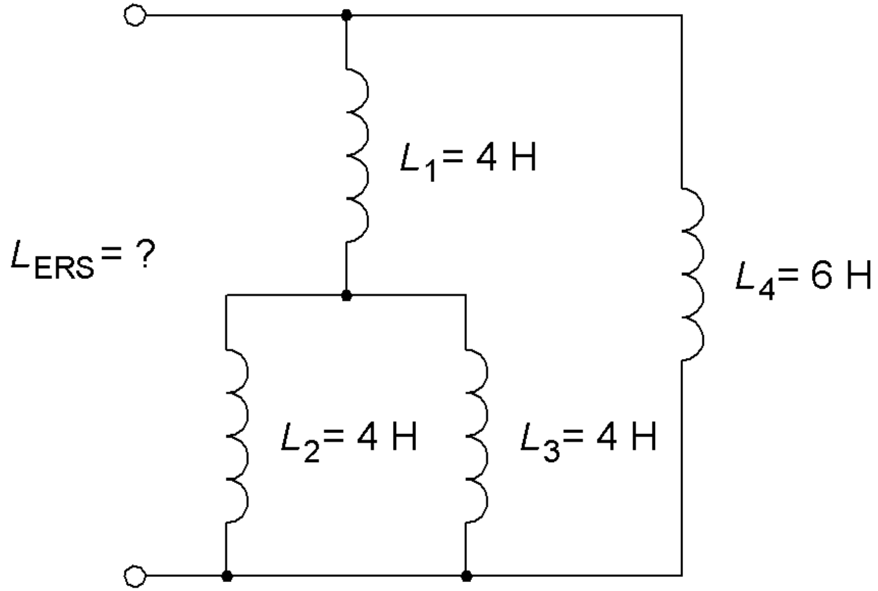


William Sandqvist william@kth.se

Series and parallel connection of inductors

(Ex. 15.6) Assuming that none of the coils parts magnetic lines of force with each other but are completely independent components, they can be treated series and parallel inductors just as if they were resistors.

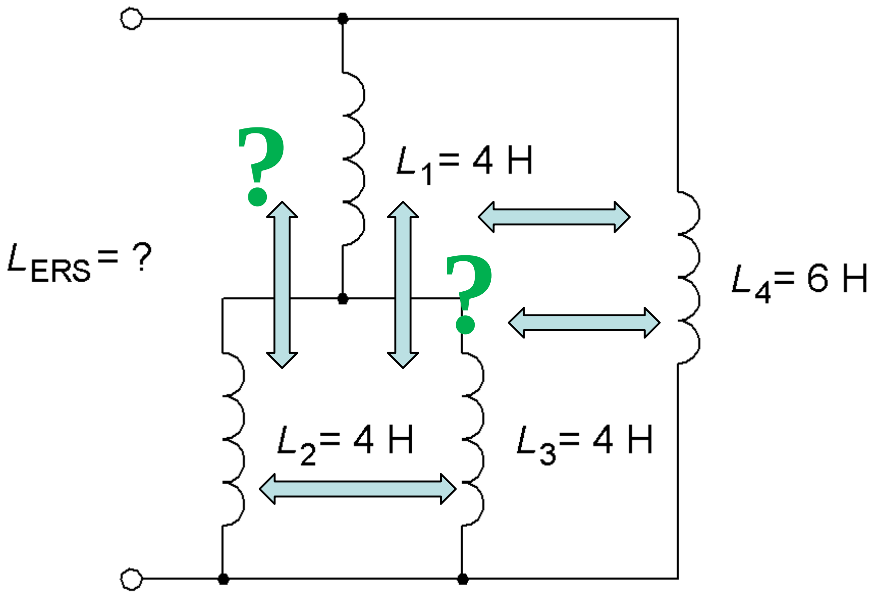
$$L_{\text{ERS}} = \frac{\left(4 + \dfrac{4 \cdot 4}{4+4}\right) \cdot 6}{4 + \dfrac{4 \cdot 4}{4+4} + 6} = 3\,\text{H}$$



Series and parallel connection of inductors?

We have previously studied serial and parallel coils as if they were completely independent components that do not share magnetic lines with each other.

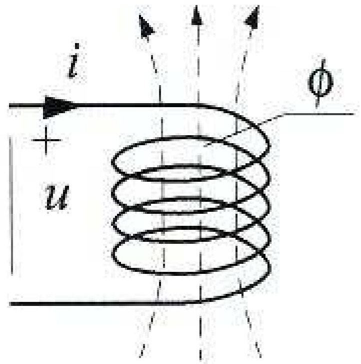
We are now treating coils with interconnected flow

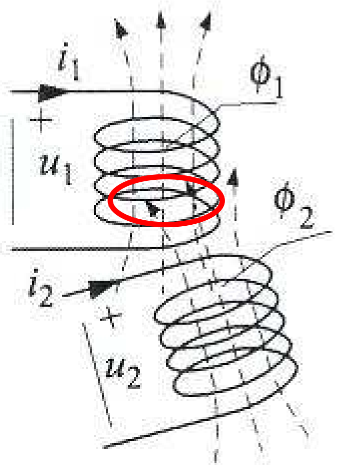


Inductive coupling

Induction

$$u = r \cdot i + \frac{\mathrm{d}\varphi}{\mathrm{d}t}$$





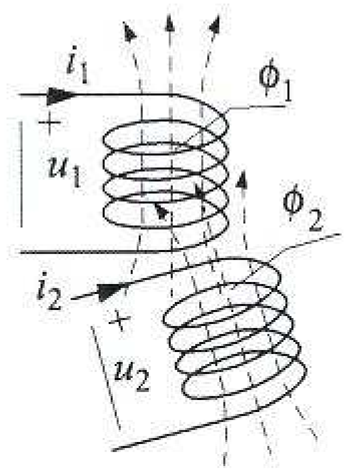
A portion of the flow in the coil 1 is interconnected with flow from the coil 2.

$$u_1 = r_1 \cdot i_1 + \frac{\mathrm{d}\varphi_1}{\mathrm{d}t} \qquad \varphi_1 = i_1 \cdot L_1 + i_2 \cdot M$$

In same way:

$$u_2 = r_2 \cdot i_2 + \frac{\mathrm{d}\varphi_2}{\mathrm{d}t} \qquad \varphi_2 = i_2 \cdot L_2 + i_1 \cdot M$$

Inductive coupling



$\pm M$ is called mutual inductance

$$u_1 = r_1 \cdot i_1 + L_1 \frac{\mathrm{d}i_1}{\mathrm{d}t} + M \frac{\mathrm{d}i_2}{\mathrm{d}t}$$

$$u_2 = r_2 \cdot i_2 + L_2 \frac{\mathrm{d}i_2}{\mathrm{d}t} + M \frac{\mathrm{d}i_1}{\mathrm{d}t}$$

jω-method:

$$U_1 = r_1 \cdot I_1 + \mathrm{j}\omega L_1 I_1 + \mathrm{j}\omega M I_2$$
$$U_2 = r_2 \cdot I_2 + \mathrm{j}\omega L_2 I_2 + \mathrm{j}\omega M I_1$$

An ideal transformer has coupling factor $k = 1$ (100%)

Coupling factor:

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

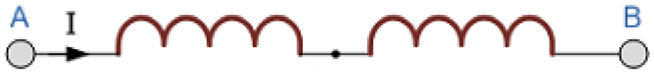
The coupling factor indicates how much of the flow a coil has in common with another coil

William Sandqvist william@kth.se

Series with mutual inductance

Derive:

$$L_1 \quad M_{12} \quad \underline{U}_{L1} \quad \underline{I}_{L1} \qquad L_2 \quad M_{21} \quad \underline{U}_{L2} \quad \underline{I}_{L2}$$



$$\underline{U}_{L1} = j\omega L_1 \underline{I}_{L1} \pm j\omega M_{12} \underline{I}_{L2} \qquad \underline{U}_{L2} = j\omega L_2 \underline{I}_{L2} \pm j\omega M_{21} \underline{I}_{L1}$$

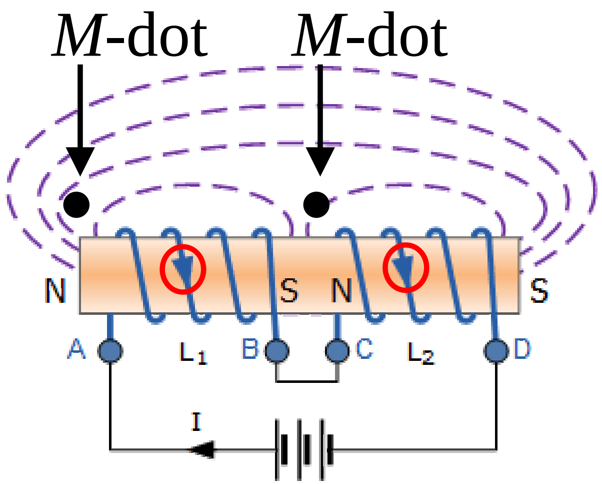
Series connection has the same current

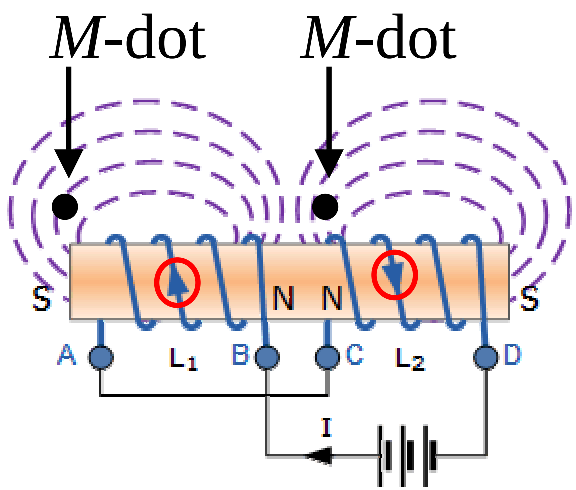
$$\underline{I}_{L1} = \underline{I}_{L2} = \underline{I} \quad \underline{U} = \underline{U}_{L1} + \underline{U}_{L2} \quad M_{12} = M_{21} = M \quad \Rightarrow$$

$$\underline{U} = \underline{I} \cdot j\omega(L_1 \pm M + L_2 \pm M)$$

$$\frac{\underline{U}}{\underline{I}} = j\omega(\boxed{L_1 + L_2 \pm 2M})$$

Series with mutual inductance





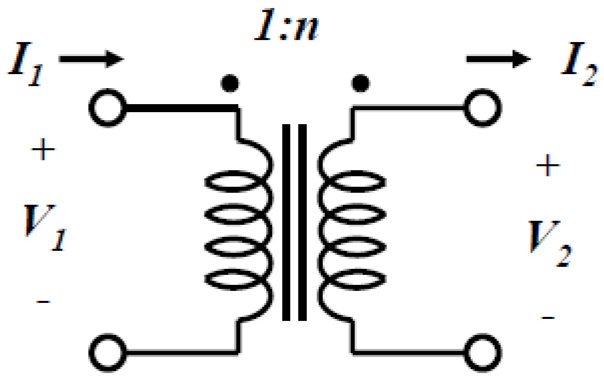
Series connection has the same current $I_1 = I_2 = I$

$$L_{TOT} = L_1 + L_2 + 2M \qquad L_{TOT} = L_1 + L_2 - 2M$$

M can can contribute or counter act to the flow, this gives $\pm$ sign. Therefore, coil winding polarity is usually indicated by a dot convention in schematics.

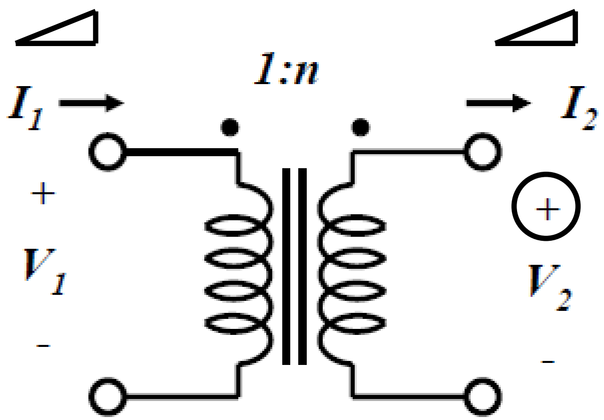
William Sandqvist william@kth.se

”Dot” convention



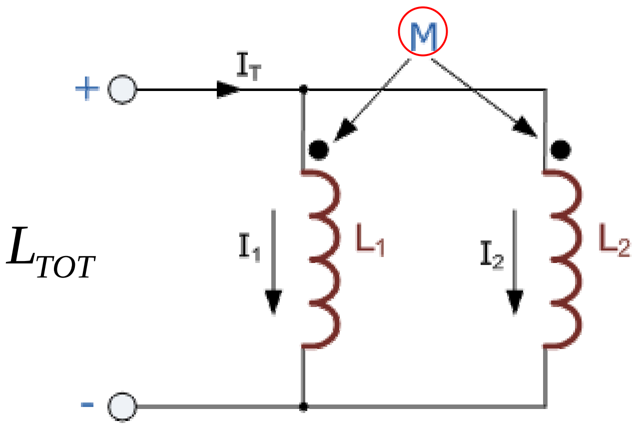
An increasing current ***in*** to a dot results in induced voltages with directions that would give increasing currents **out** of other dots.

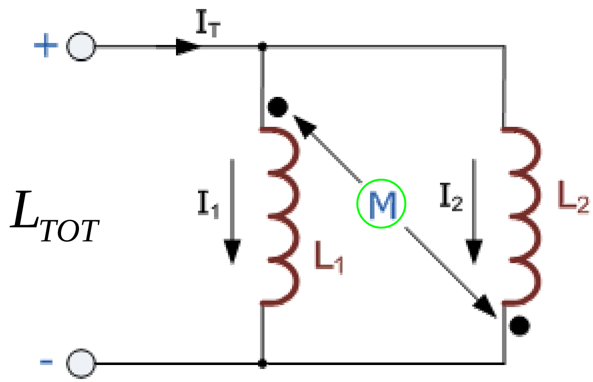
”Dot” convention



An increasing current ***in*** to a dot results in induced voltages with directions that would give increasing currents **out** of other dots.

In parallel with mutual inductance





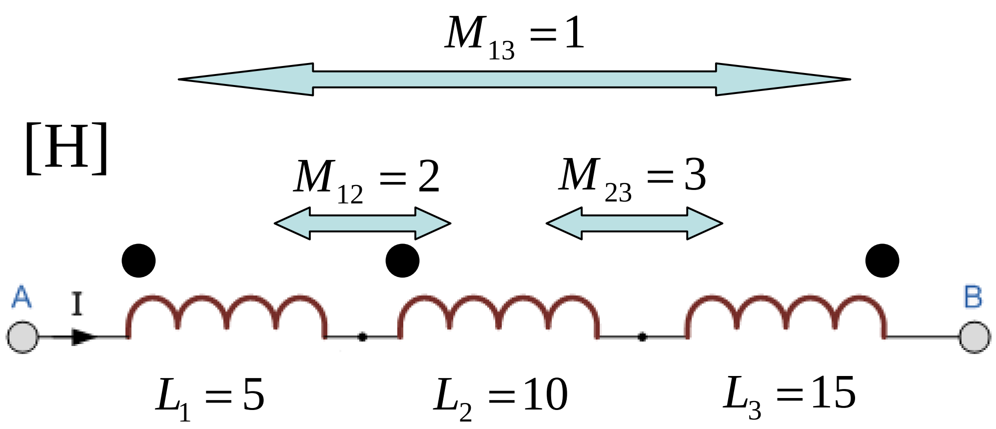
Parallel connected coils

$$L_{TOT} = \frac{L_1 \cdot L_2 - M^2}{L_1 + L_2 - 2M}$$

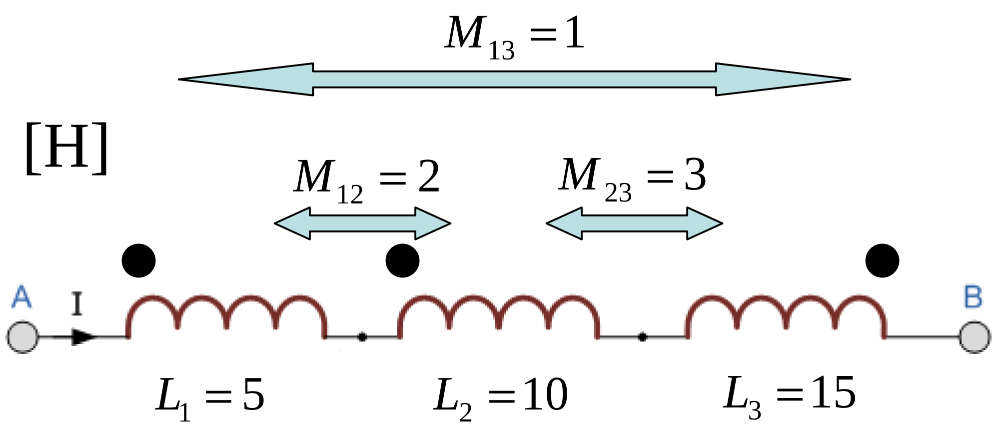
Antiparal conected coils

$$L_{TOT} = \frac{L_1 \cdot L_2 - M^2}{L_1 + L_2 + 2M}$$

Ex. 15.7   Series connection



Ex. 15.7   Series connection



$L_{TOT} =$

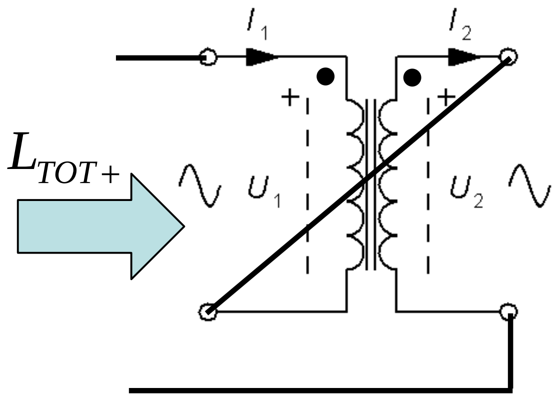
$L_1 + M_{12} - M_{13} +$

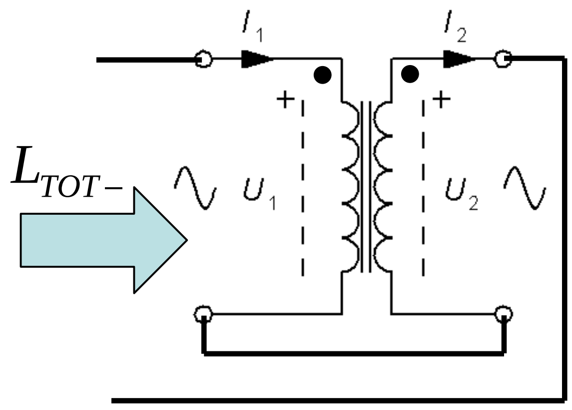
$L_2 + M_{12} - M_{23} +$

$L_3 - M_{23} - M_{13} =$

$= 5 + 2 - 1 + 10 + 2 - 3 + 15 - 3 - 1 = 26$ [H]

Measuring the mutual inductance?

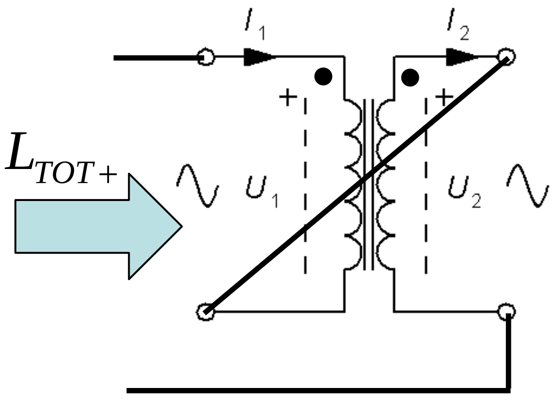


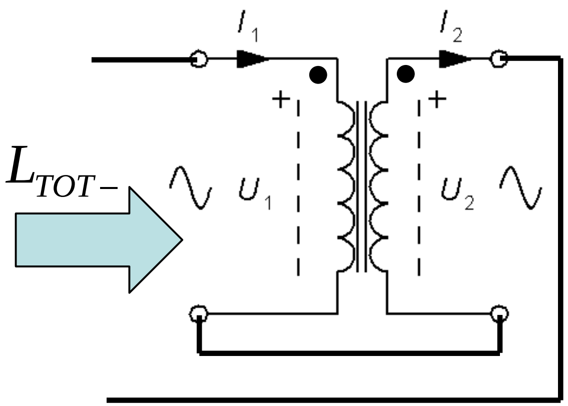


$$L_{TOT+} = L_1 + L_2 + 2M$$

$$L_{TOT-} = L_1 + L_2 - 2M$$

Measuring the mutual inductance?





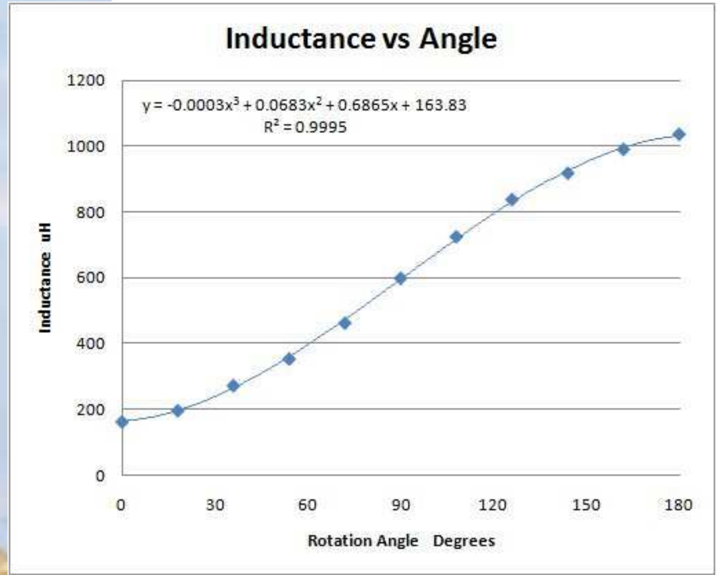
$$L_{TOT+} = L_1 + L_2 + 2M$$

$$L_{TOT-} = L_1 + L_2 - 2M$$

$$M = \frac{L_{TOT+} - L_{TOT-}}{4}$$

William Sandqvist william@kth.se

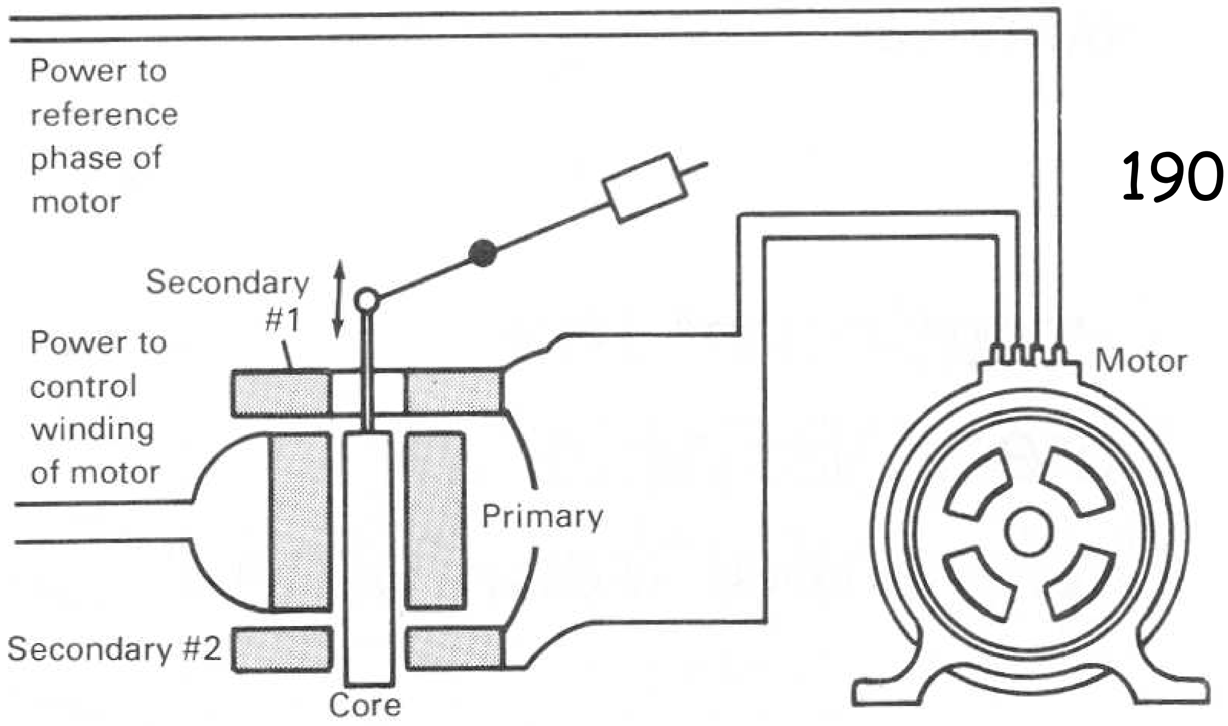
Variometer (to an antique radio)



$$L_{TOT} = L_1 + L_2 \pm 2M$$
$$M = f(\alpha)$$

William Sandqvist william@kth.se

A bad actuator can become a good sensor



1906

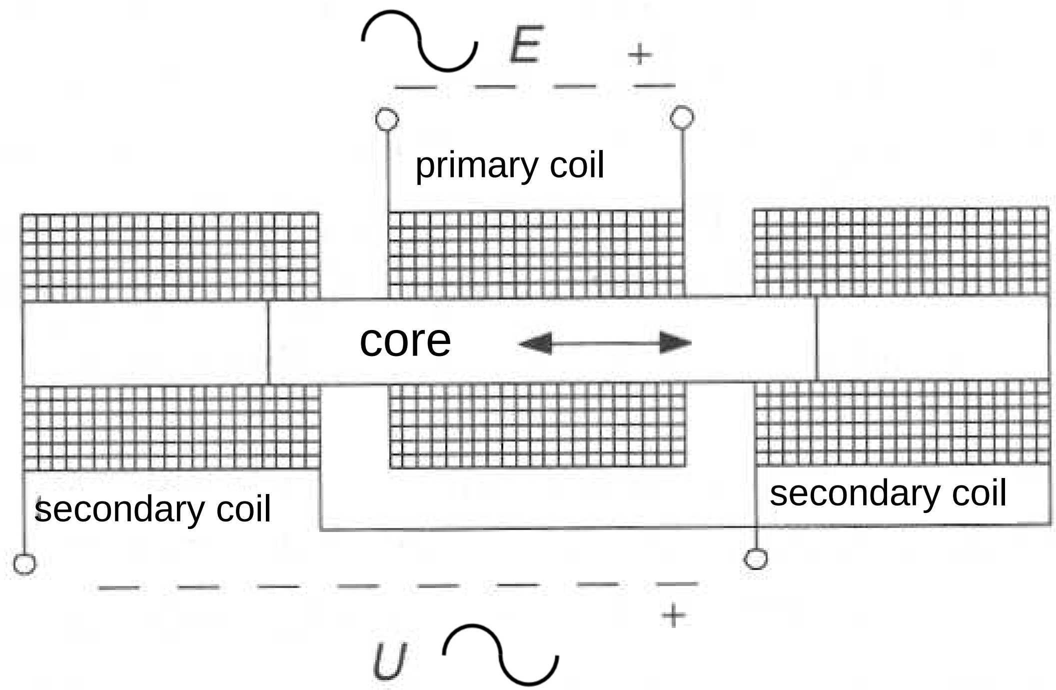
Porter & Currier patent (simplified), the earliest variable differential transformer.

William Sandqvist william@kth.se

The industry's "rugged" position sensor

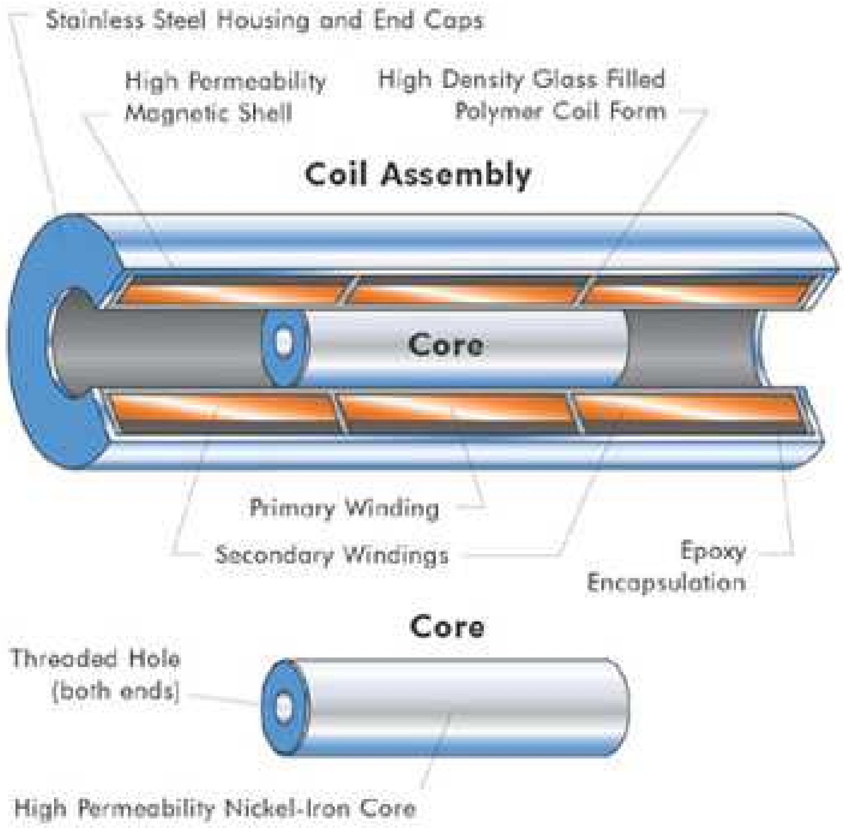
Differential transformer

LVDT Linear Variable Differential Transformer

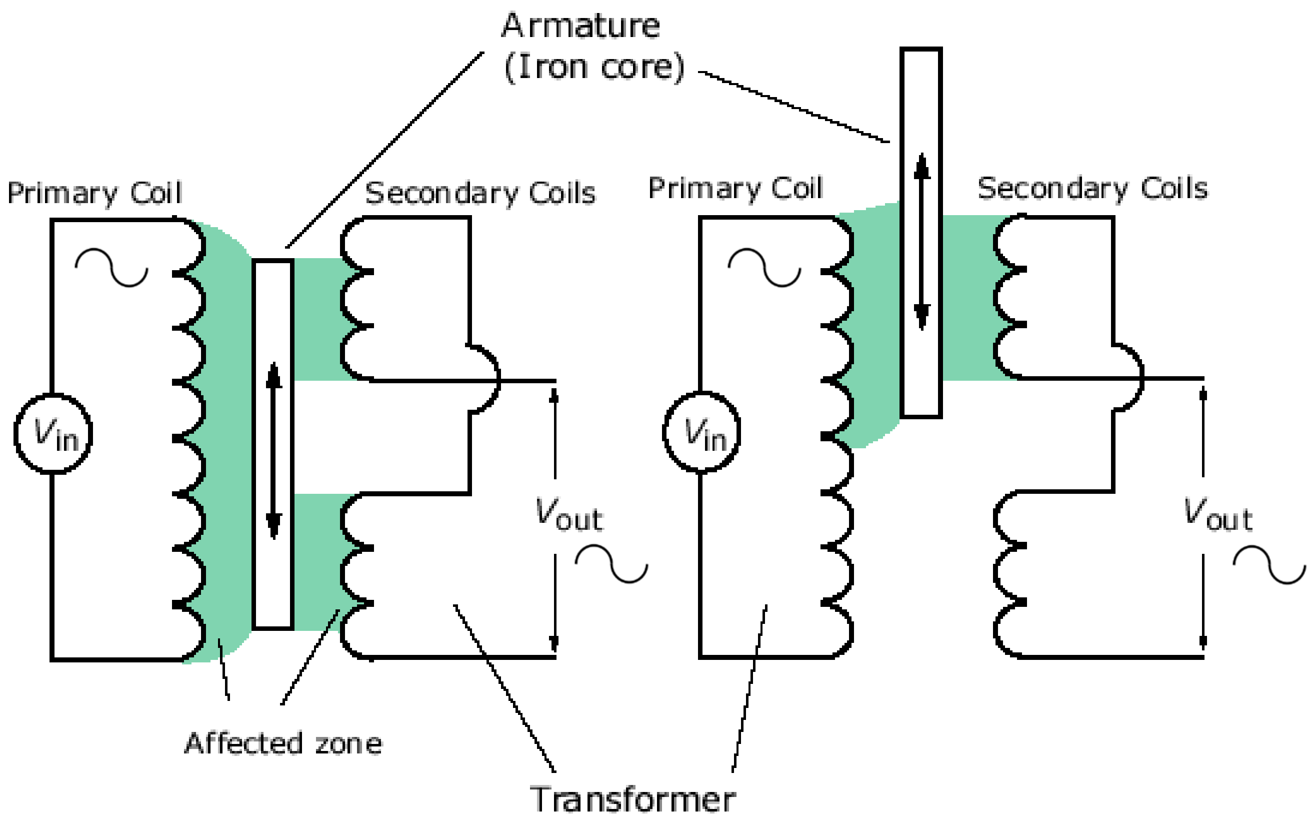


The secondary coils are connected in series but with opposite polarity – when the core is in the middle $U = 0$.

LVDT design

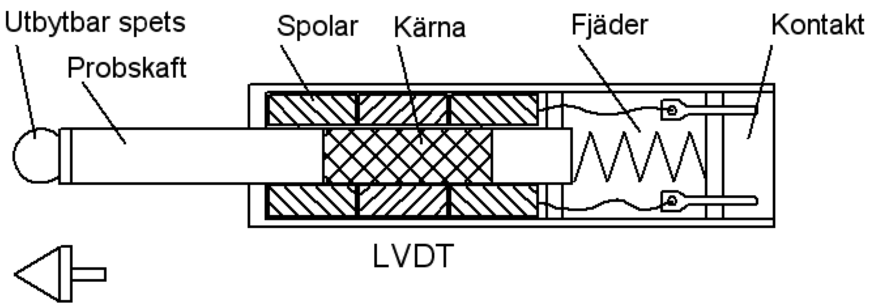

Stainless Steel Housing and End Caps
High Permeability Magnetic Shell
High Density Glass Filled Polymer Coil Form
Coil Assembly
Core
Primary Winding
Secondary Windings
Epoxy Encapsulation
Core
Threaded Hole (both ends)
High Permeability Nickel-Iron Core

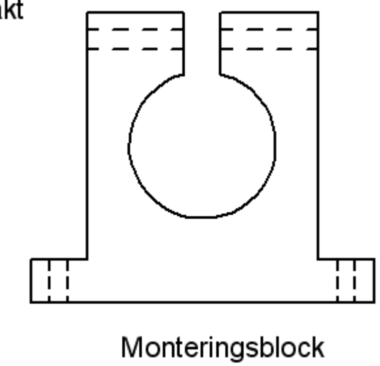
LVDT principle

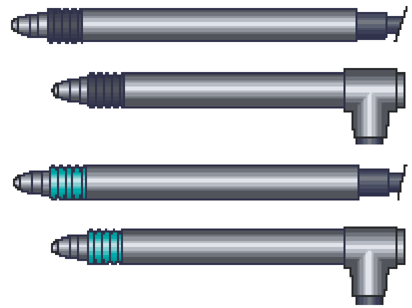


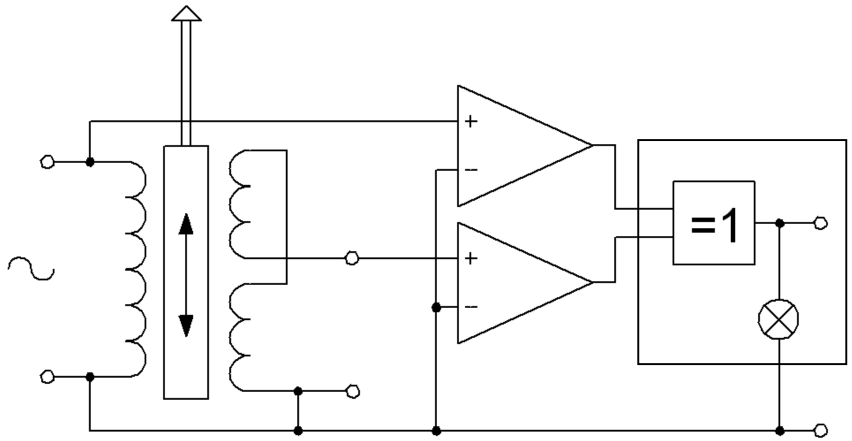
The output voltage is relatively high – it makes this a popular sensor …

LVDT probe



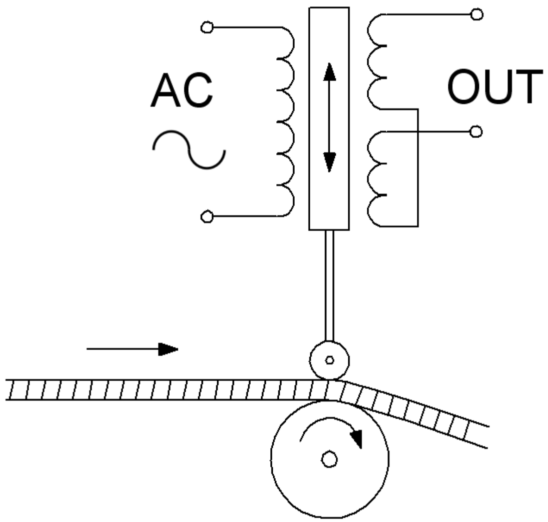






Output signal changes **phase 180°** exactly when the core pass the middle point.

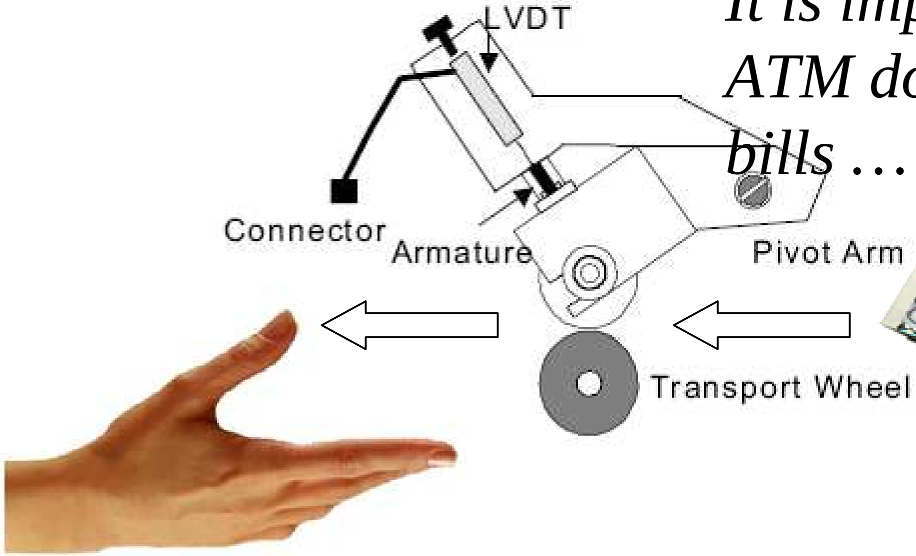
A XOR-gate kan **indicate** this change.



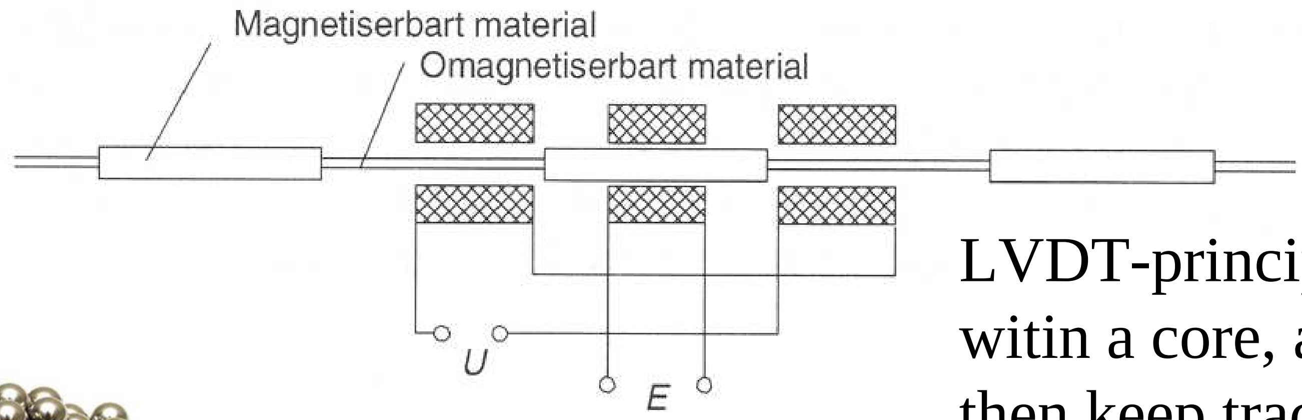
A LVDT probe can keep track on that the thicknes is correct.

Guess application?

It is important to ensure that the ATM does not distribute "double" bills …

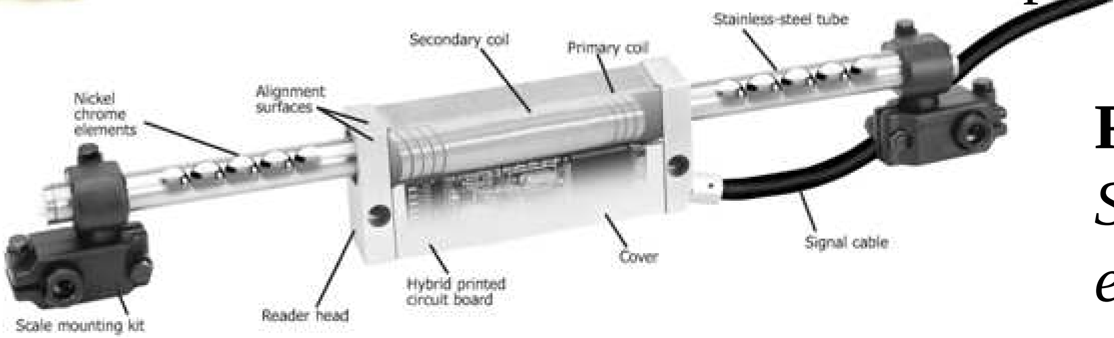


Periodic differential transformer



LVDT-principel witin a core, and then keep track on how many cores that have passed.

A similar sensor?



Renywell
Spherical encoder

William Sandqvist william@kth.se